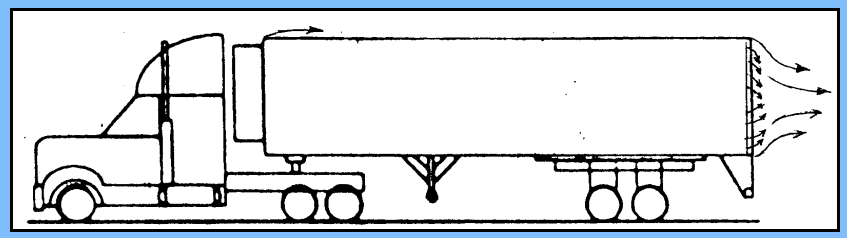
PNEUMATIC AERODYNAMIC DEVICES TO IMPROVE THE PERFORMANCE, EFFICIENCY, ECONOMICS AND SAFETY OF HEAVY VEHICLES

DOE Third Workshop on Heavy Vehicle Aerodynamics

by
Robert J. Englar
Principal Research Engineer
Georgia Tech Research Institute
Aerospace, Transportation & Advanced Systems Laboratory
Atlanta GA

Pneumatic Aerodynamics

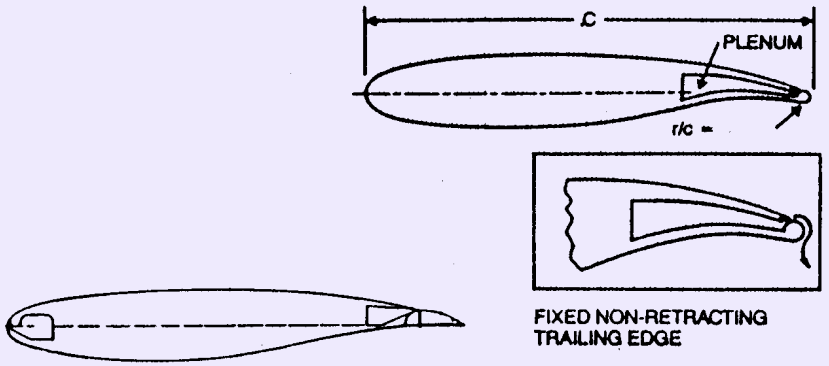
GTRI FutureCar Pneumatics



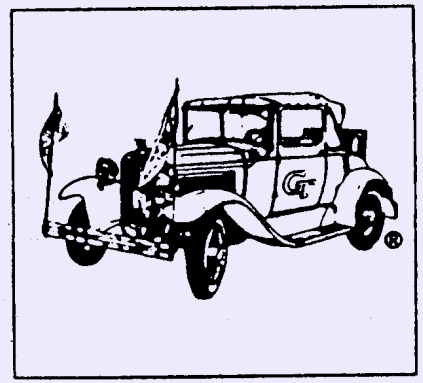
Advanced Heavy Vehicles

OUTLINE OF PRESENTATION

- Introduction: Potential of Aerodynamic Improvements For Commercial Vehicles
- Pneumatic Aerodynamics
- Lessons from Application of Pneumatic Aerodynamics to Automobiles, FutureCar
- Current DOE Program: "Pneumatic Aerodynamics for Heavy Vehicles"
- Pneumatic Aerodynamics Applied to Large Commercial Vehicles
- Conclusions and Recommendations

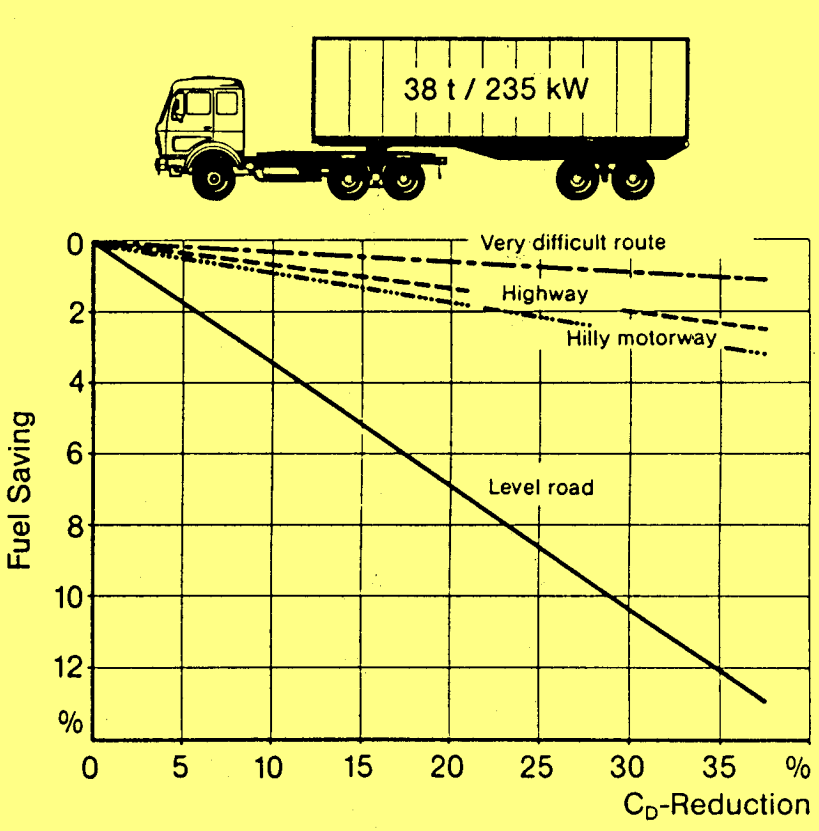


Advanced Pneumatic Aerodynamics

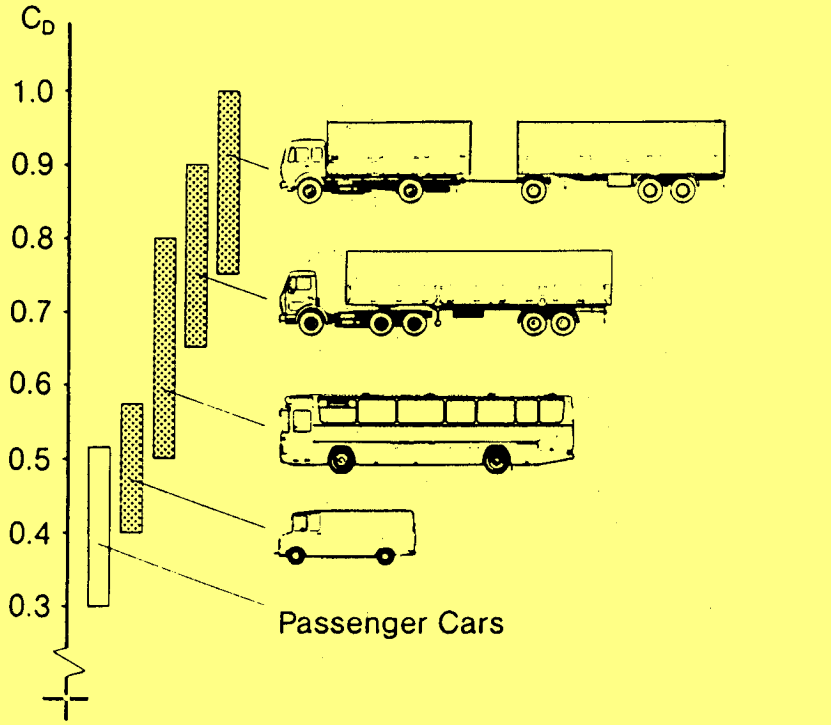


GT Automotive Experience

HEAVY VEHICLE EFFICIENCY INCREASE FROM IMPROVED AERODYNAMICS: DRAG REDUCTION



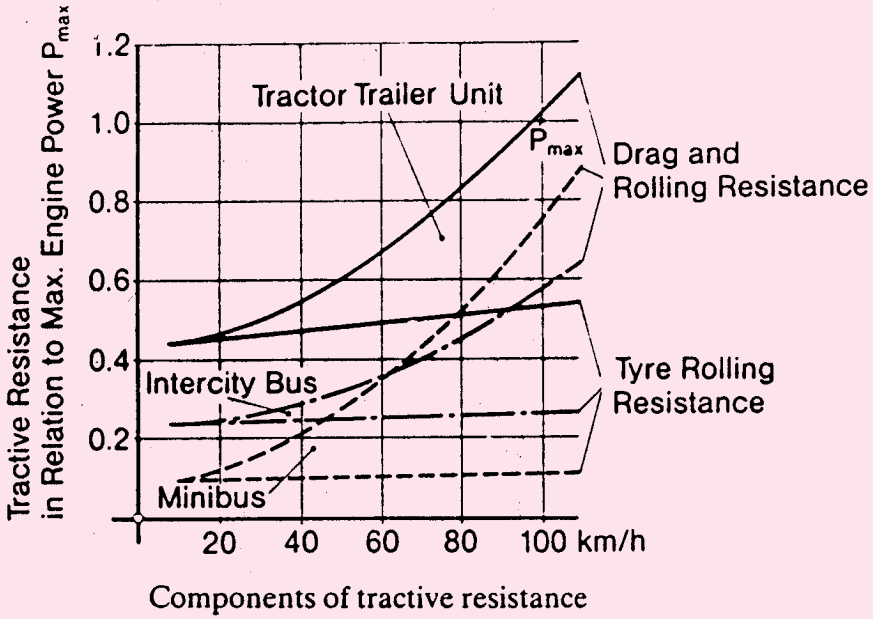
Influence of drag on fuel consumption of a 38-tonne semitrailer



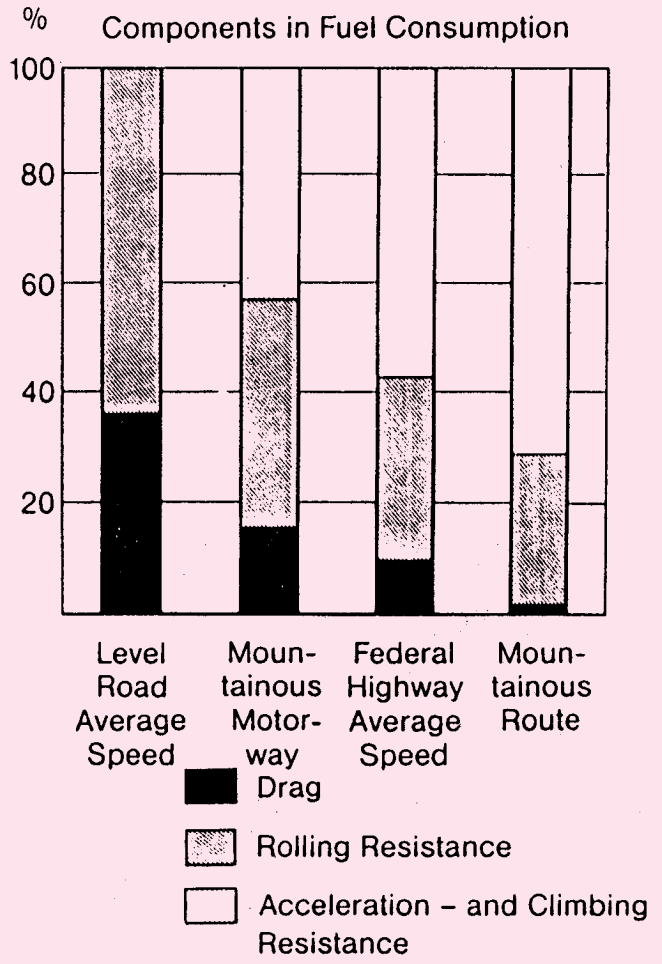
Drag coefficients of different commercial vehicles

from Hucho, "Aerodynamics of Road Vehicles," 1990

EFFICIENCY INCREASE FROM IMPROVED AERODYNAMICS: COMPONENTS OF TRACTIVE RESISTANCE



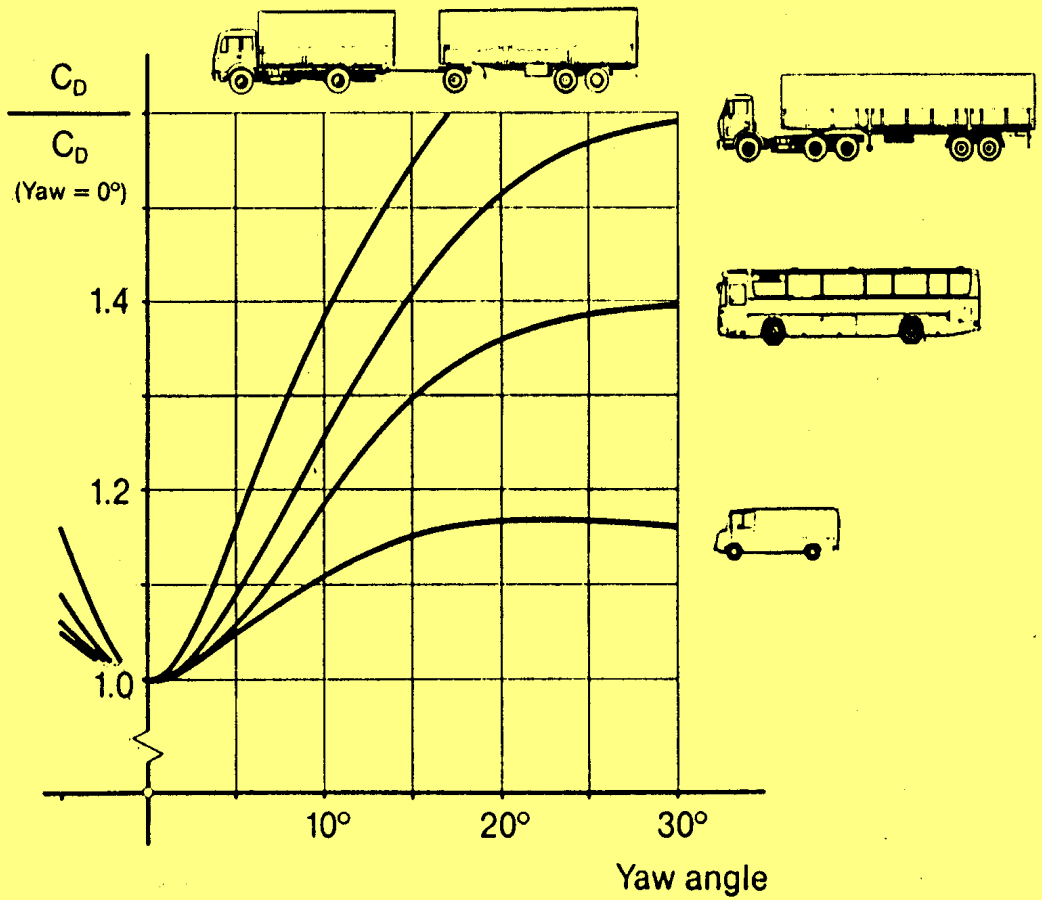
Components of tractive resistance



Fuel consumption of a 38-tonne tractor-semitrailer to overcome tractive resistance

from Hucho, "Aerodynamics of Road Vehicles", 1990

VEHICLE DIRECTIONAL SENSITIVITY TO THE WIND

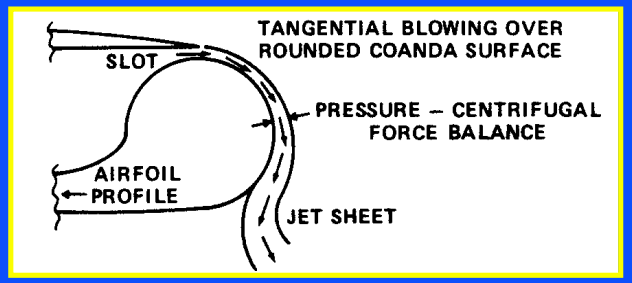


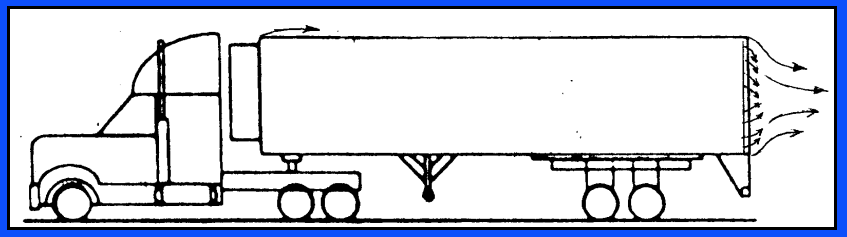
Drag versus yaw of different vehicle types

from Hucho, "Aerodynamics of Road Vehicles," 1990

Circulation Control Technology

- Circulation Control is an innovative flow control technology that can dramatically improve aerodynamic/aeropropulsive performance and simplify mechanical complexity through pneumatic means.
- Circulation Control technology has previously been developed and flight-demonstrated for military/NASA aircraft (A-6/CCW, H2/CCR, CCW/USB, NOTAR).
- Leveraging GTRI "Future Car" IRAD investments, GTRI AERO is successfully transitioning this technology for NASAand non-DOD, non-military markets.
- New DOE award for "Pneumatic Aero-dynamic Devices for Heavy Vehicles" is first part of a multi-phase concept-demonstration program.





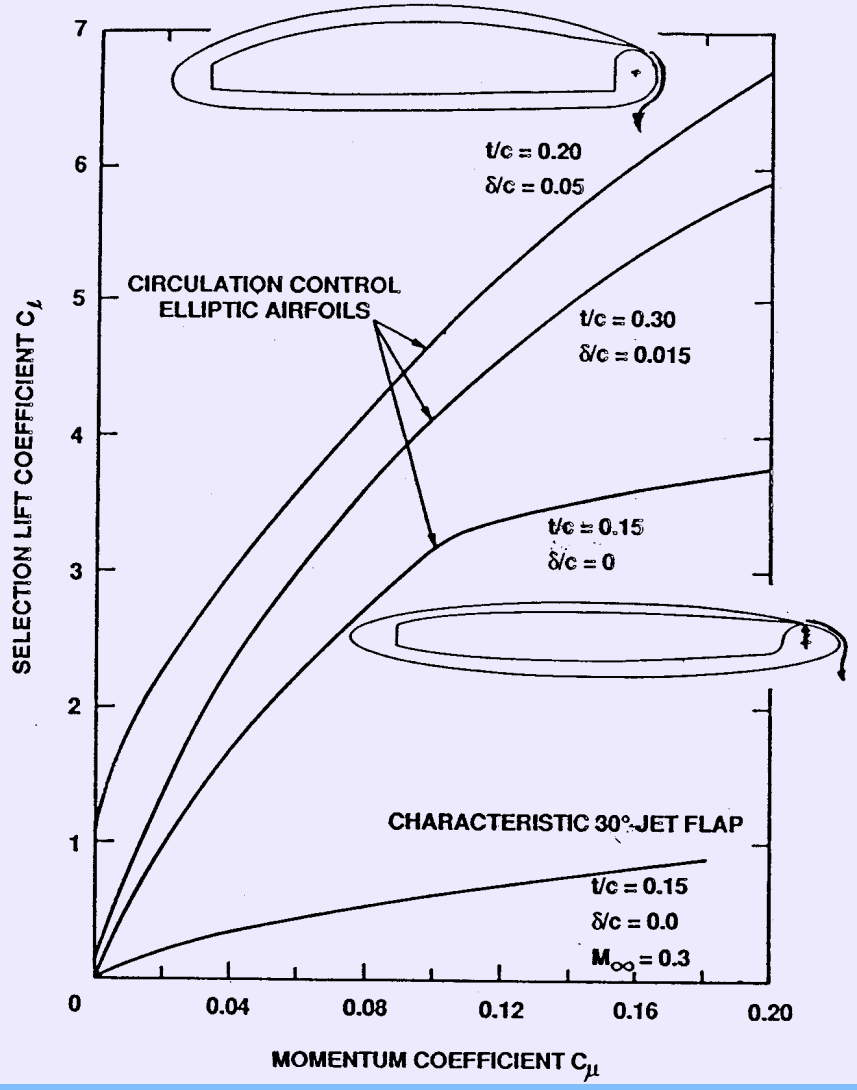
BACKGROUND OF CIRCULATION CONTROL AERODYNAMICS EXPERTISE, NOW RESIDING AT GTRI

1967-1968: "Imported" from England, (C.C. Stowed Rotor at NGTE) by U.S. Navy, David Taylor Naval Ship R&D Center	Aerodynamics Lab., DTNSRDC
1968-1972: Development of C.C. Airfoils for Rotary Wing (CCR, X-Wing)*	DTNSRDC
1973-1975: C.C. Wing High-Lift Airfoil Development*	DTNSRDC
1975-1979: A-6/CCWing STOL Demonstrator Flight Test	DTNSRDC
1979-1984: Advanced CCW and CCW/Powered Lift Programs*	DTNSRDC
1984-1989: Advanced CCW, Powered Lift & Pneumatic Concepts*	Advanced Flight Sciences Dept. Lockheed-Georgia Co
1989-1999: Advanced Aerodynamic Concept Development*	Aerospace Sciences Lab Georgia Tech Research Institute
1990-1999: In-Ground-Effect Unlimited Hydroplane & Race Car Development *	Aerospace Sciences Lab, GTRI
1994-1999: Pneumatic Automobile Research & DOE Programs*	Aero Sciences Lab, GTRI
1993-1999: CCW for Advanced Transports (NASA) & High Speed Aircraft (AF) *	Aero & Transportation Lab, GTRI

* Miscellaneous advanced pneumatic concepts and applications in other categories were developed in this time period. A large number of invention disclosures produced more than 15 patents.

- **GTRI's Robert J. Englar** led or was heavily involved in every one of these developments.

Typical Blown-Lift-Generation Capabilities of Two-Dimensional Circulation Control Elliptic Airfoils at $\alpha = 0°$



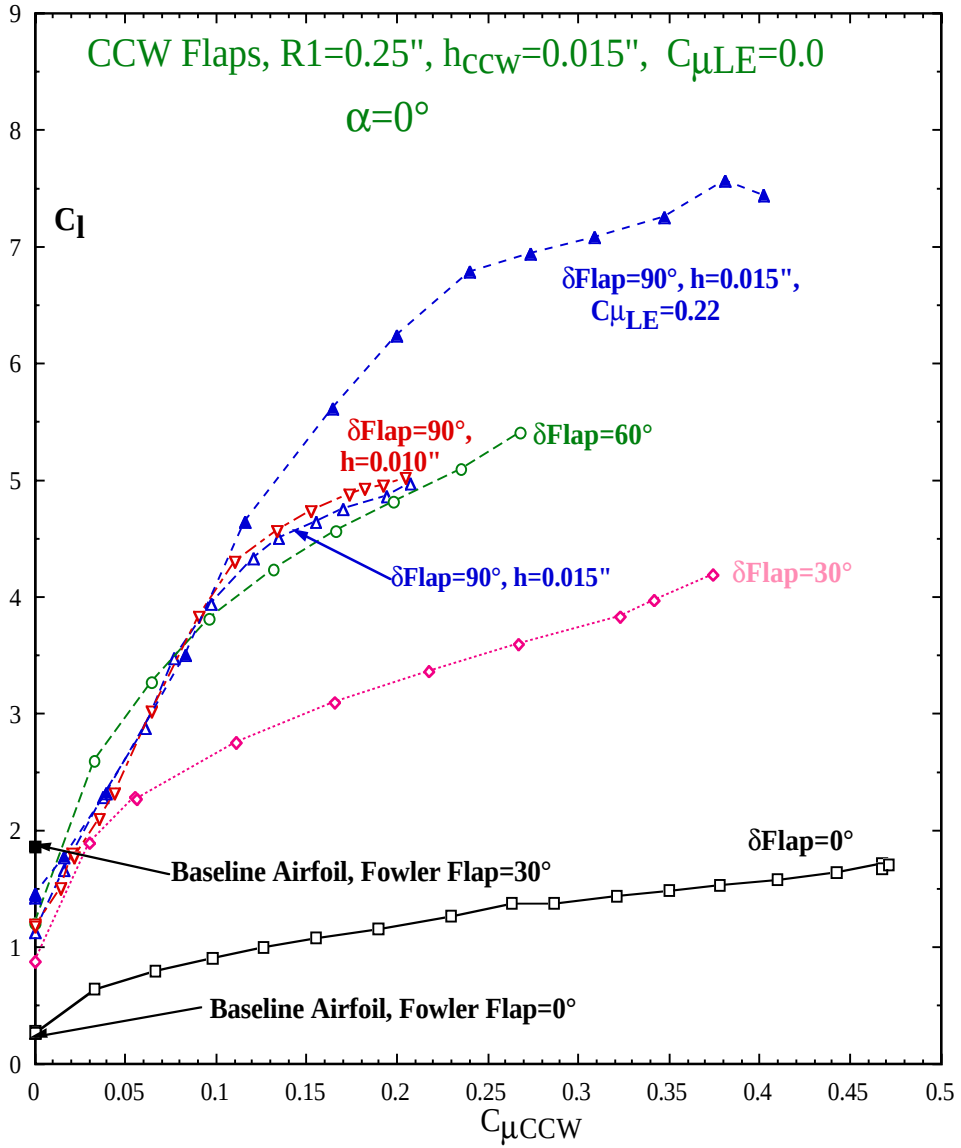
Momentum Coefficient,
$C\mu = mVj/(qc)$

A-6 / CIRCULATION CONTROL WING
STOL DEMONSTRATOR AIRCRAFT & FLIGHT TEST RESULTS

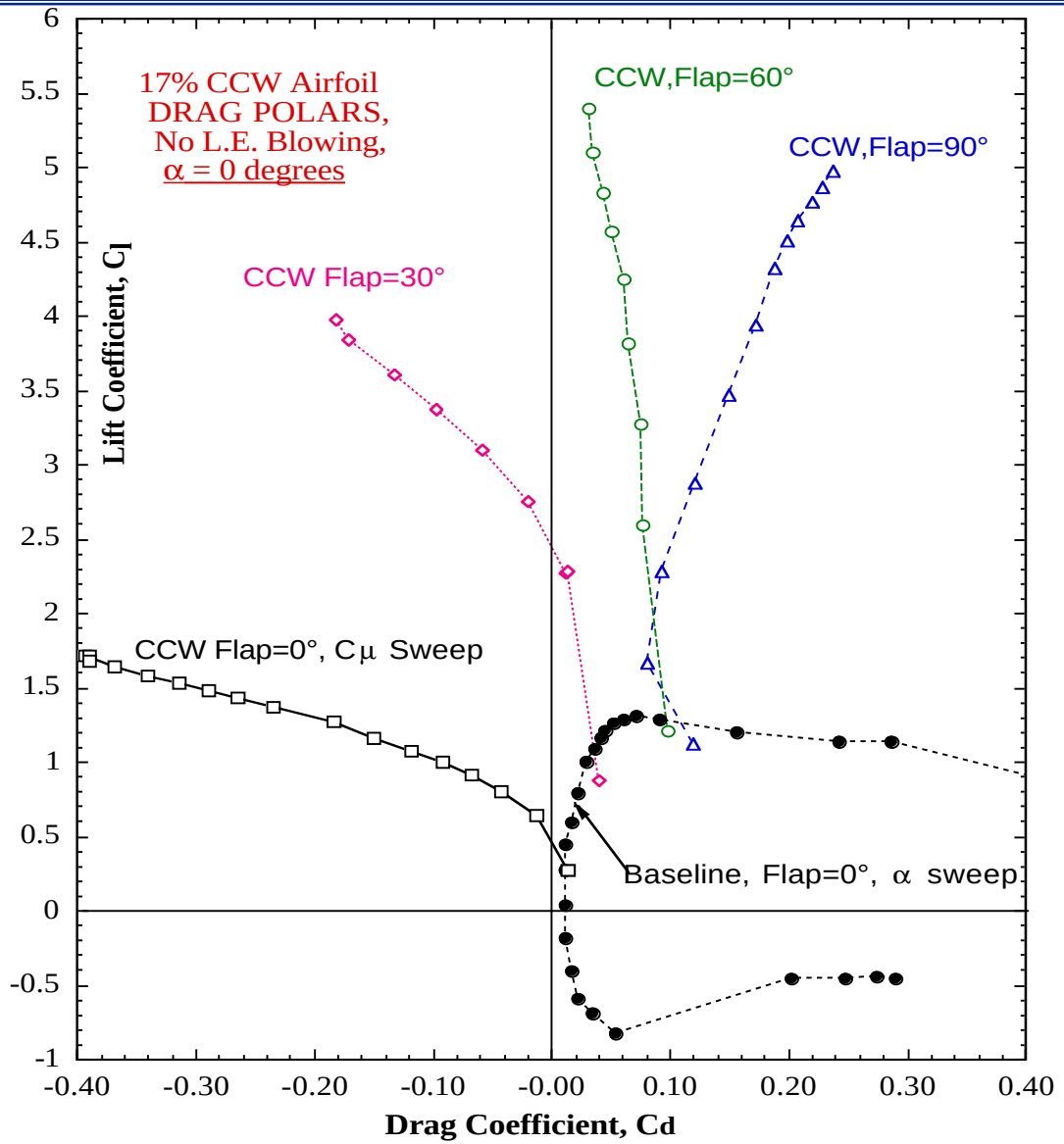
FLIGHT TEST RESULTS: 140% Increase in Usable C_L
30-35% Reduction in Takeoff & Approach Speeds
60-65% Reduction in Takeoff & Landing Ground Roll
75% Increase in Liftable Takeoff Payload

CONFIRMATION OF FULL-SCALE CCW

2-Dimensional CCW AIRFOIL with DUAL-RADIUS FLAPS, LIFT VARIATION WITH BLOWING AT α=0°

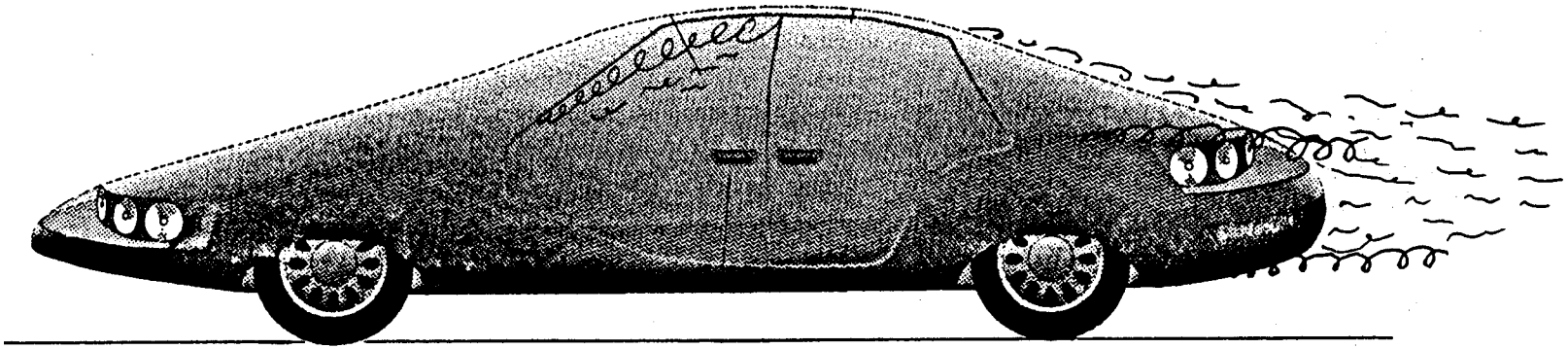


2-D CCW AIRFOIL with DUAL - RADIUS FLAPS, DRAG POLARS, THE PENALTY FOR LIFT ??



GTRI FutureCar Pneumatic Aerodynamics Project (Now Completed & Concepts Confirmed at GTRI)

GOAL: Apply Aerodynamic Blowing Techniques to a Streamlined Automobile Configuration to Improve its Aerodynamic and Stability Characteristics



2 Patents Issued to GTRI, 1 Pending

TYPICAL AERODYNAMIC PROBLEM AREAS FOR AUTOMOBILES:

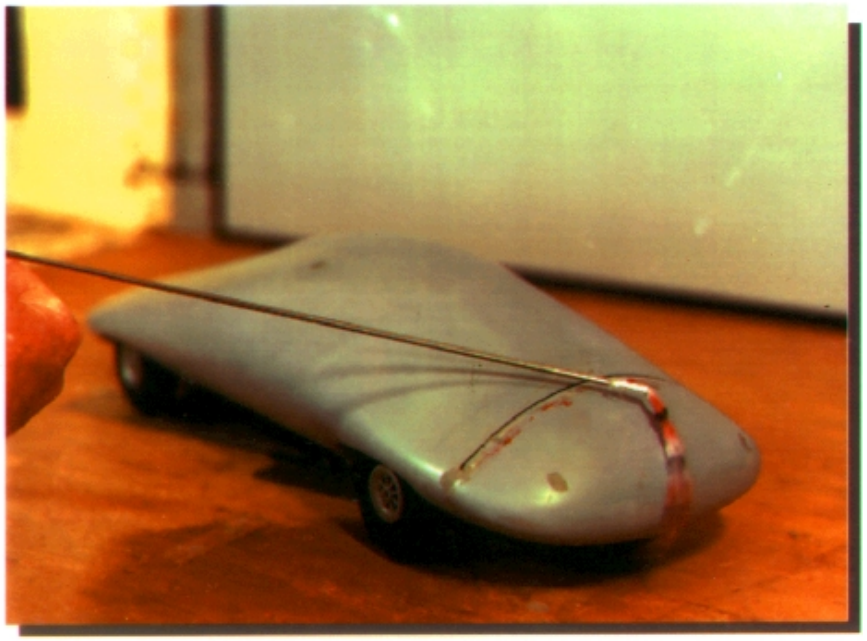
- DRAG CAUSED BY FLOW SEPARATION AND VORTEX FORMATION
- NOISE CAUSED BY FLOW SEPARATION AND VORTEX FORMATION
- DIRECTIONAL SENSITIVITY & INSTABILITY CAUSED BY YAW, SIDE FORCES & GUSTS
- POWER CONSUMPTION BY PROPOSED DRAG REDUCTION DEVICES & CONTROLS
- EXCESSIVE UPPER SURFACE LIFT--INCREASED DOWNLOAD REQUIRED

UNIQUE SOLUTION: MULTI-PURPOSE APPLICATIONS OF PNEUMATIC (BLOWN) AERODYNAMIC TECHNOLOGY

Blown Model Installation in GTRI Tunnel on a 2-point Yaw Strut with Air Supply Line, and Showing Blown Ground Effect Simulation

Experimental Confirmation of Pneumatic Aerodynamic Concepts on GTRI FutureCar Model, Showing Blowing Jet Turning

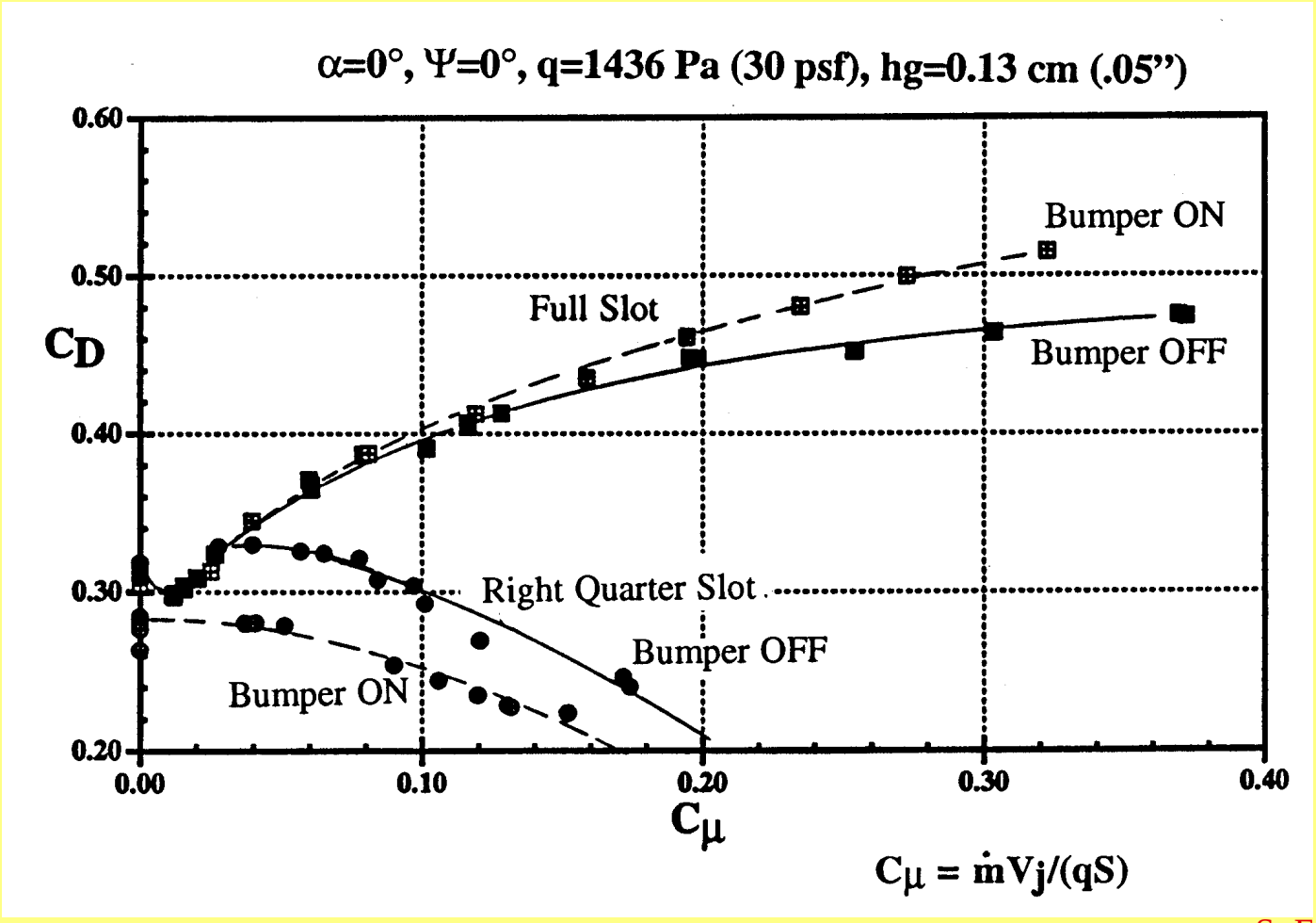
Blowing Slot Adjustment and Checkout in the GTRI M odel Test Facility



Blowing Slot & Flow Turning Over Trunk of Streamlined Car Model

Effect of Blowing on GTRI FutureCar Drag at Yaw Angle = 0° and Pitch Angle = 0°, Various Configurations

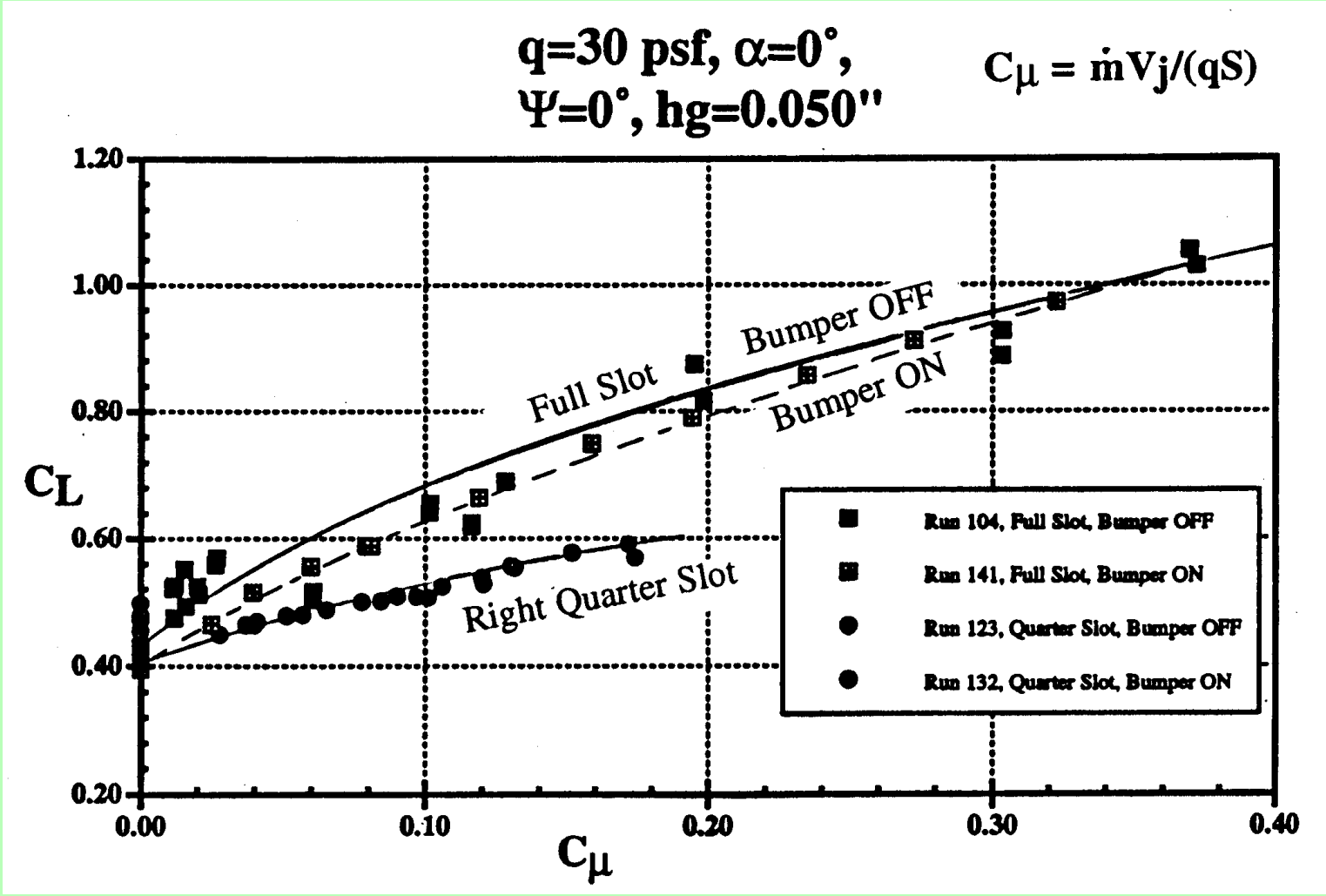
Drag Decreased(Cruise) or Increased (Braking), Depending on Configuration and Blowing



S=Frontal area

Effect of Blowing on GTRI FutureCar Lift at Yaw Angle= 0° and Pitch Angle = 0°, Various Configurations

Lift Increased by Blowing; Download (-Lift) Increased by Blowing Lower Surface Slot



Potential For Pneumatic Aerodynamics Applied To Heavy Vehicles, as Confirmed at GTRI Aerospace and Transportation Lab

Experimentally Confirmed Blowing Benefits on GTRI FutureCar:

- Drag reduction of 35%; increase of 100%, depending on configuration
- Lift increase of more than 170%; similar download (-lift) increases
- Lateral/directional stability restored at large sidewind angles

Potential Benefits of CC Pneumatics Applied to Heavy Vehicles:

- Pneumatic devices on back of vehicle, **blowing slots on all sides**
- Separation control and base pressure recovery for **drag reduction, or**
  Base suction for **drag increase**
- Additional lift for **rolling resistance reduction** ($F_R = \mu N$, N=W-L), **or**
  Reduced lift for **traction and braking**: instantaneously **switchable**
- Partial slot blowing for **roll control & lateral stability**
- One-side blowing for **yaw control & directional stability**
- **Aerodynamic control** of all three forces and all three moments
- **Splash, spray & turbulence reduction**; **reduced hydroplaning**
- **No moving parts -** no drag on components
- Short aft addition **- no length limitation**
- Use **existing** on-board compressed **air sources**

Contracted Project 450000155, DOE OHVT through ORNL

Development and Evaluation of Pneumatic Aerodynamic Devices to Improve the Performance, Economics, Stability, and Safety of Heavy Vehicles

Objective

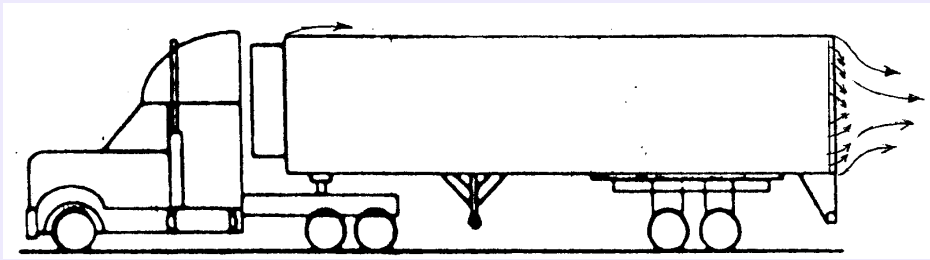
Apply previously-confirmed aircraft/automotive pneumatic aerodynamic technology to the **design of an appropriate tractor-trailer config. incorporating pneumatic devices**.

Conduct **experimental proof-of-concept wind-tunnel evaluations** to verify effectiveness on Heavy Vehicles for **increased performance, economics, stability, and safety.**

The resulting technology is then to be **transferred** to the Heavy Vehicles industry for full-scale operational evaluation.

Conduct: A 27- month **experimental/analytical evaluation program and feasibility study to rapidly confirm these potential benefits**, and then make them available for **transfer** to users in the Heavy Vehicle industry.

GTRI FutureCar Pneumatic Aerodynamics



Proposed Pneumatic Heavy Vehicle Applications

Contracted Program Tasks, Now Underway at GTRI; Funded by DOE, OHVT

- Task 1 - **CFD Analysis and Design of Pneumatic Devices and Configurations**
  Modify existing GTRI/GIT viscous flow pneumatic CFD codes
  Analyze pneumatic configurations and aid in design of advanced blown devices

- Task 2 - **Conduct Preliminary Systems Analysis**
  Use CFD and existing data base to predict aerodynamic performance of Pneumatic Heavy Vehicles, with and without blowing
  Evaluate blowing requirements and potential air sources

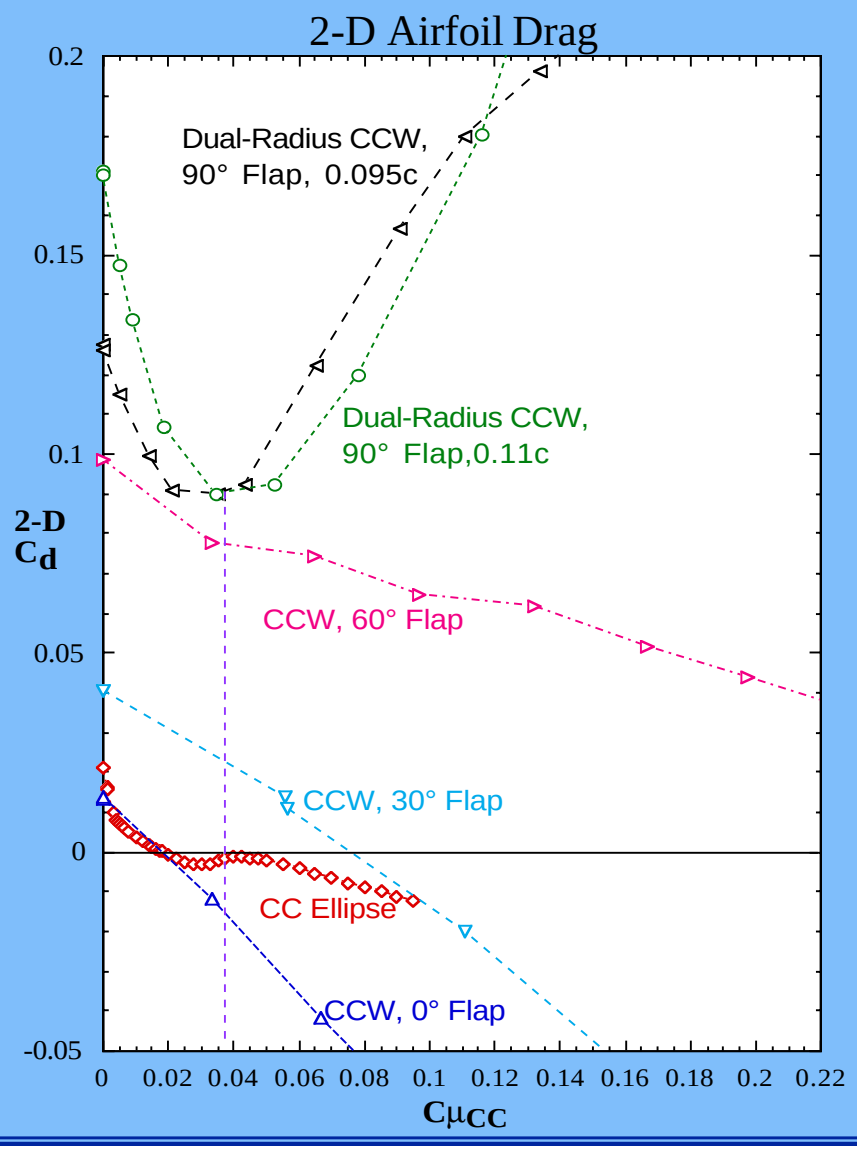
- Task 3 - **Develop Pneumatic Heavy Vehicle advanced configuration design**
  Use above results to design Pneumatic Heavy Vehicle configuration

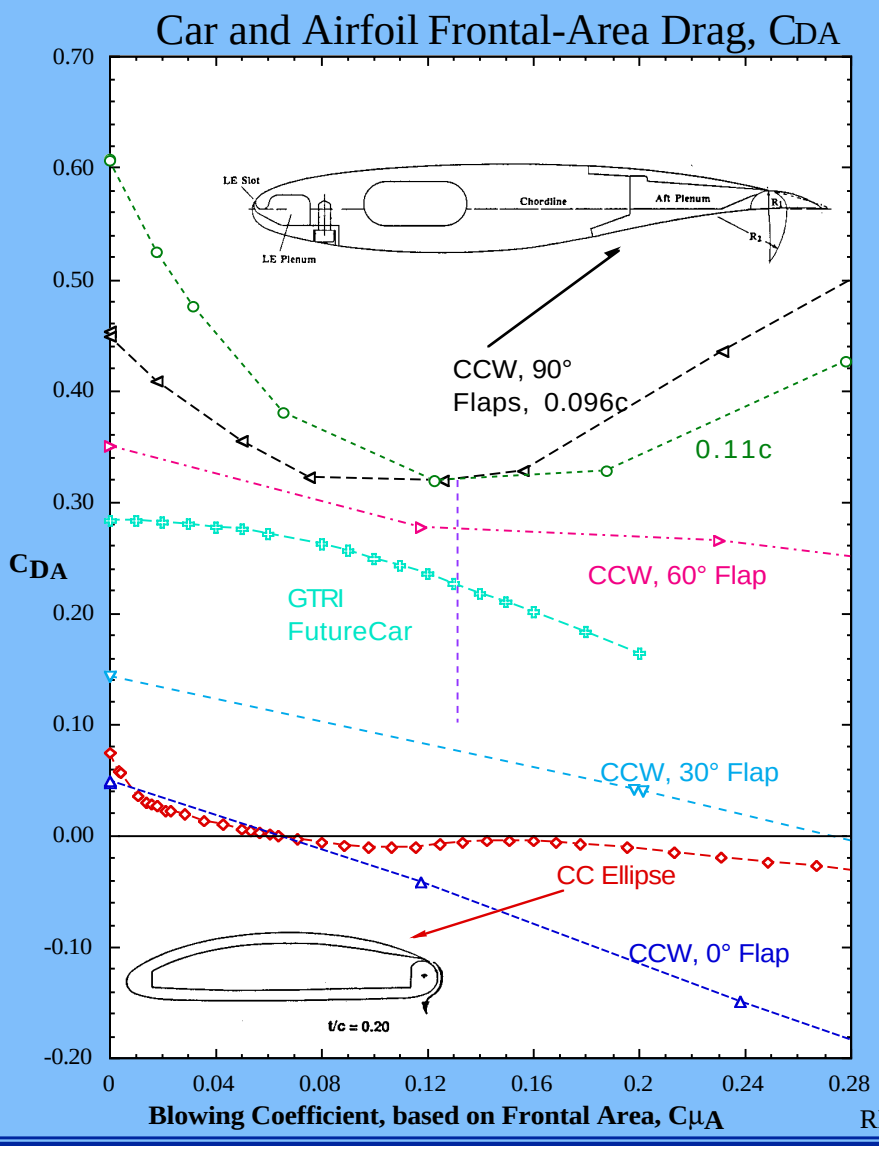
- Task 4, 5 - **Conduct Wind-Tunnel Model Design, Fabrication and Proof-of-Concept Wind Tunnel Evaluations** (Baseline vs Pneumatic)

- Task 6 - **Conduct Data Reduction and System Analyses**

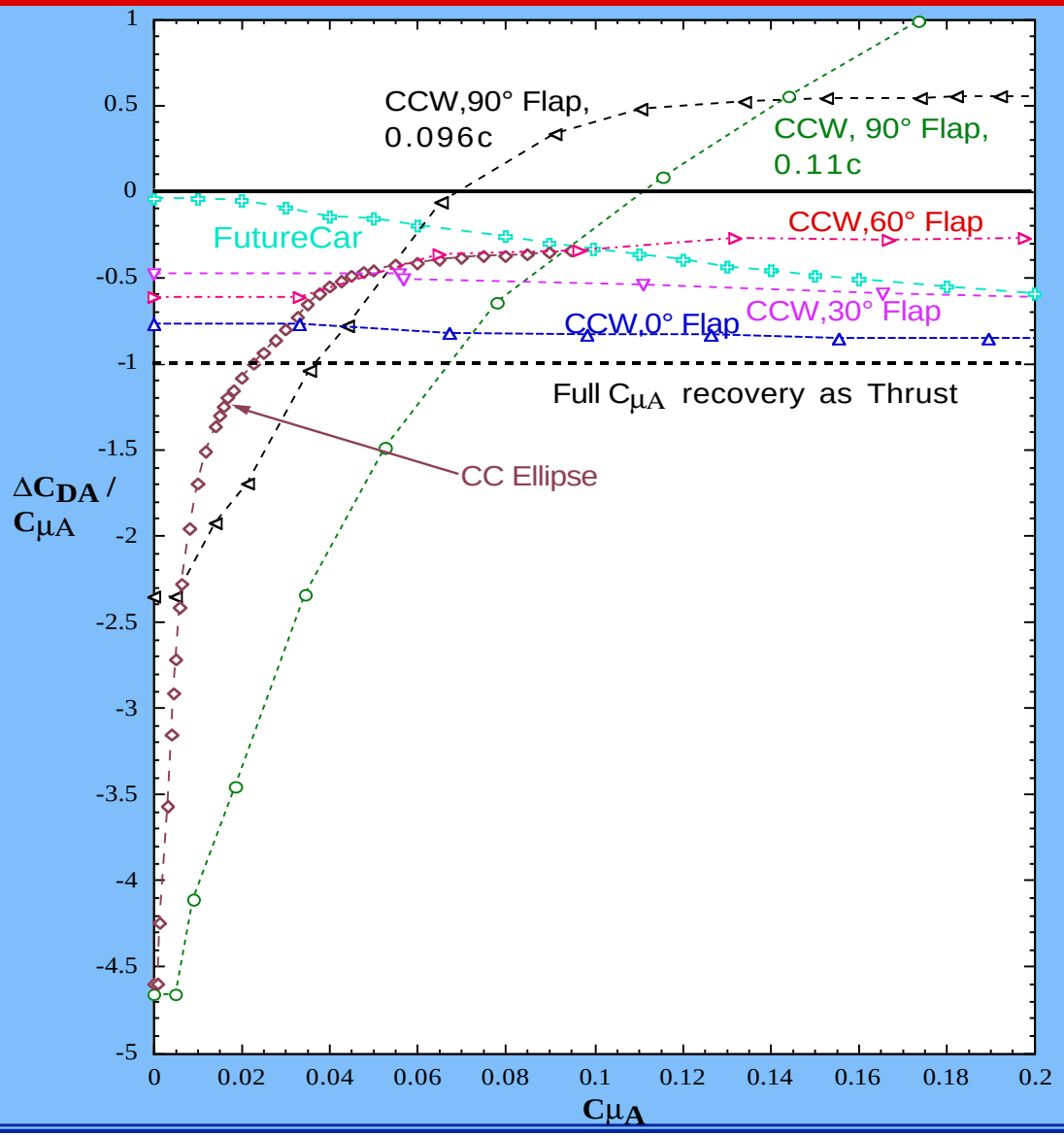
- Task 7 - **Provide Technology Transfer to Users and Industry**

CC Airfoil and Pneumatic Car Drag Reduction/Variation with Blowing at $\alpha = 0°$: Baseline for Truck Studies

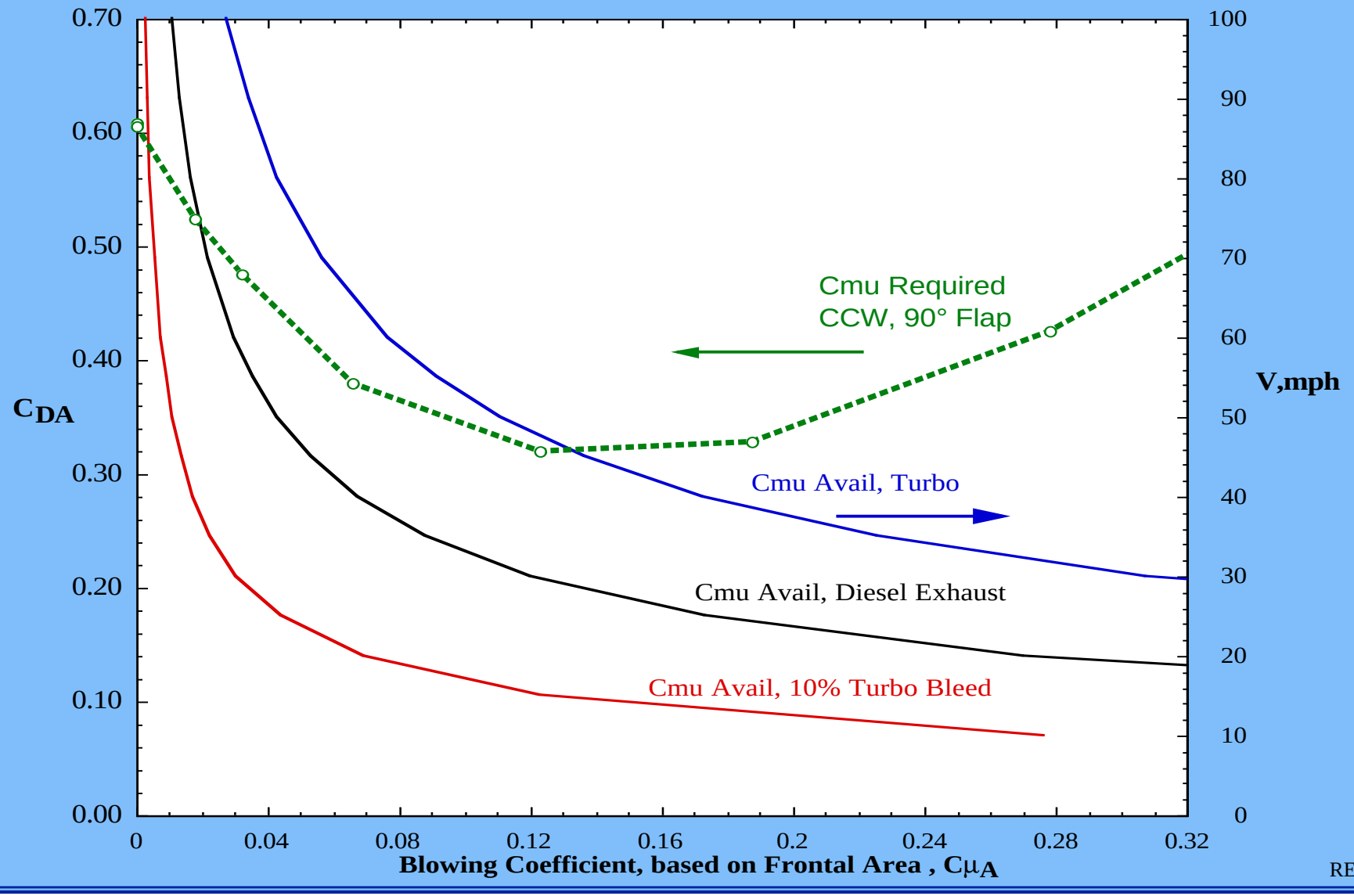




Drag Reduction Efficiency with Blowing at $\alpha = 0°$, (based on Frontal Area)



Sample Drag Variation with Blowing at α = 0°, and Available Sources of Cμ from Engine Exhaust or Turbo

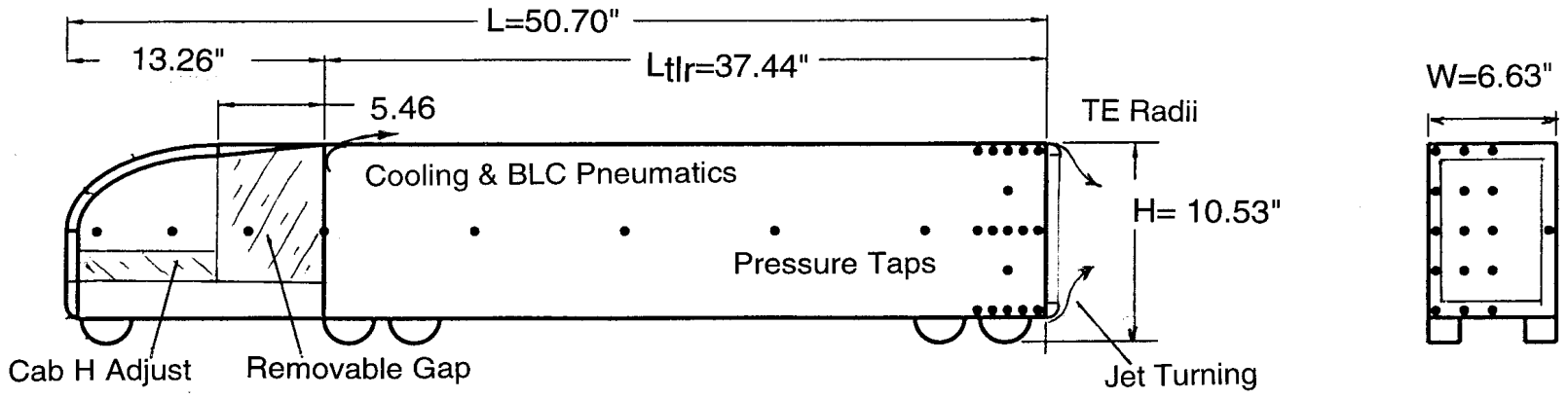


GTRI Pneumatic Heavy Vehicle
Wind Tunnel Model Scaling, Based on GTS Model

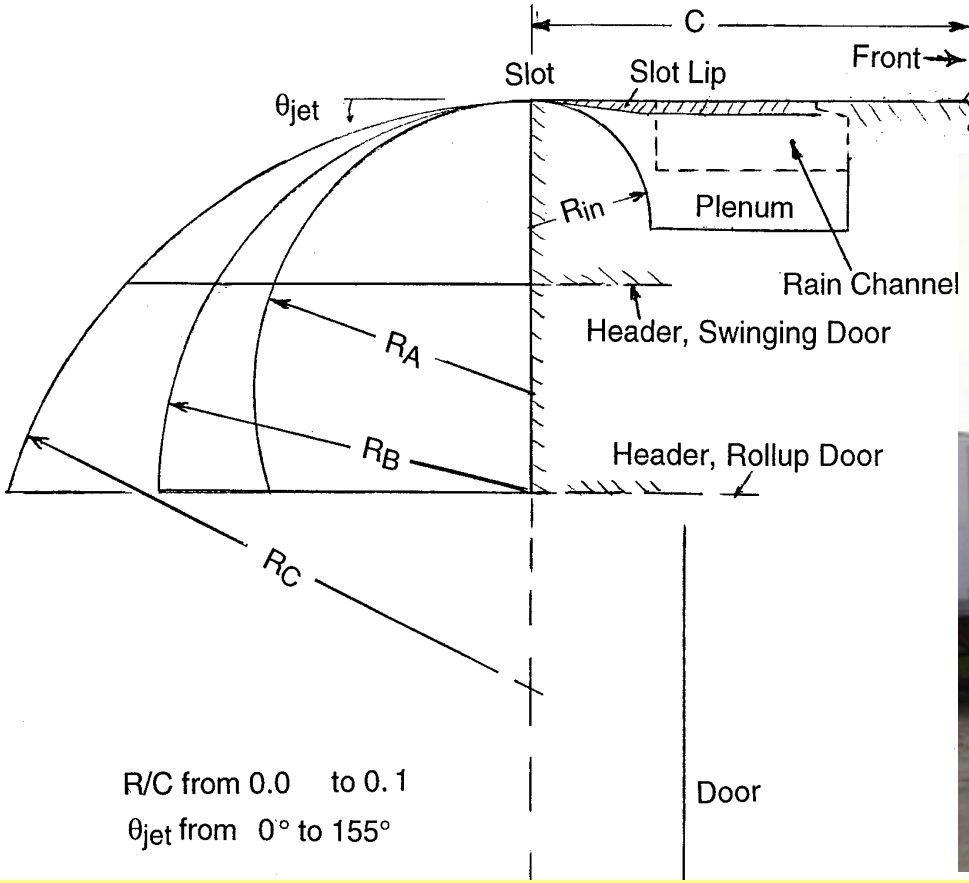
Full Scale: W=8.5', H=13.5' , $L_{TRAILER}$=48', L_{RIG}=>65', V=70 mph, Re_{TLR}=29.56x10^6

Blockage	W,in.	H,in.	Scale	$L_{TRAILER}$,in.	L_{RIG},in.	$Re_{TRAILER}$ / 10^6 (V=70mph)	$Re_{TRAILER}$ / 10^6 (q=50psf)
0.10	9.31	14.79	.0913	52.59	71.21	2.67	5.48
0.08	8.33	13.23	.0816	47.00	63.65	2.39	4.90
0.06	7.21	11.46	.0707	40.72	55.15	2.07	4.25
0.051	**6.63**	**10.53**	**.0650**	**37.44**	**50.70**	**1.90**	**3.90**
0.05	6.58	10.46	.0645	37.15	50.31	1.89	3.87
0.04	5.89	9.35	.0577	33.24	45.01	1.69	3.47

Planned GTRI 0.065 Scale Model



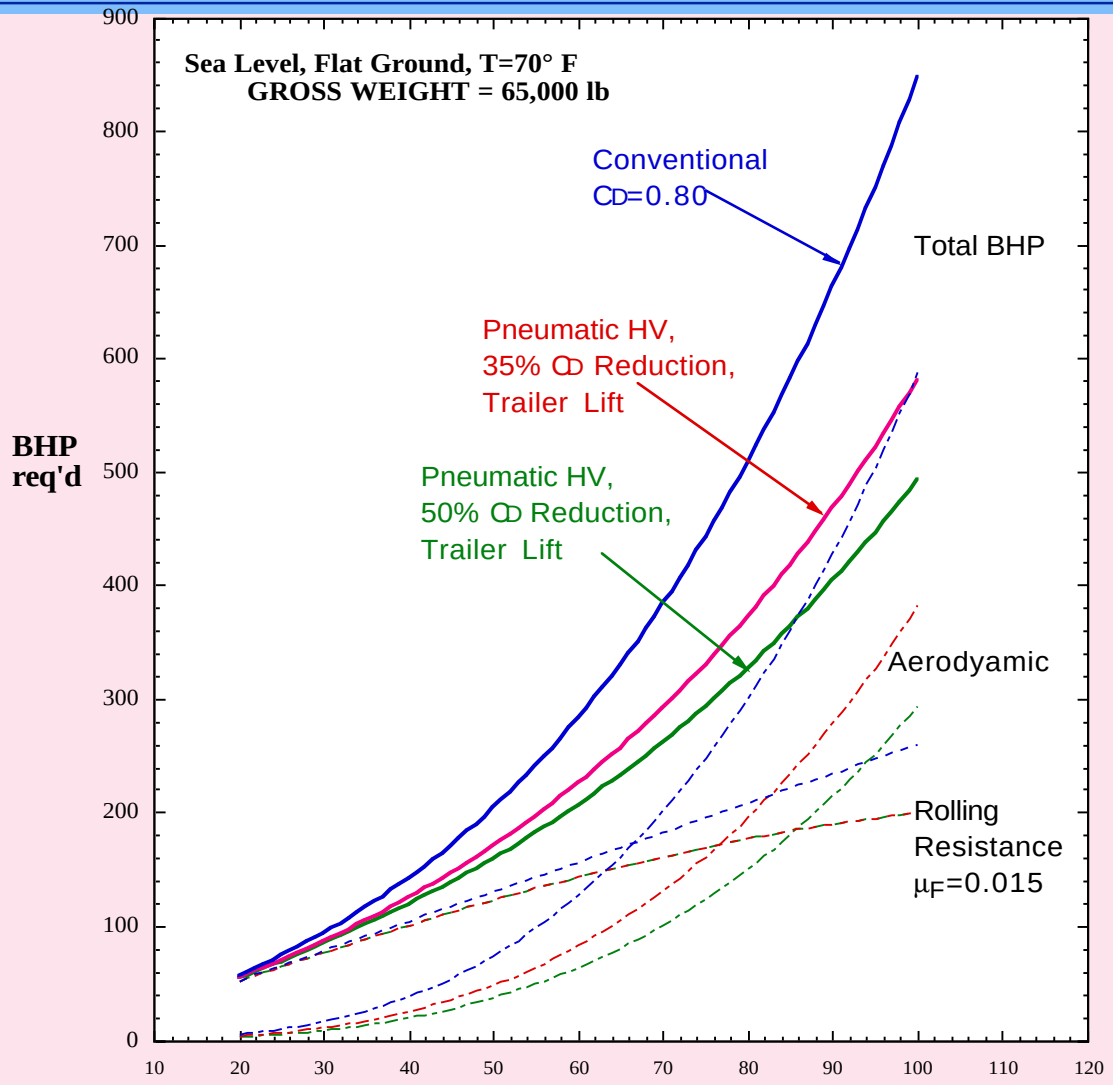
Trailing Edge Designs for Pneumatic Trailer Configuration



Candidate Pneumatic Trailing Edge Geometries

Current Trailer Door Designs

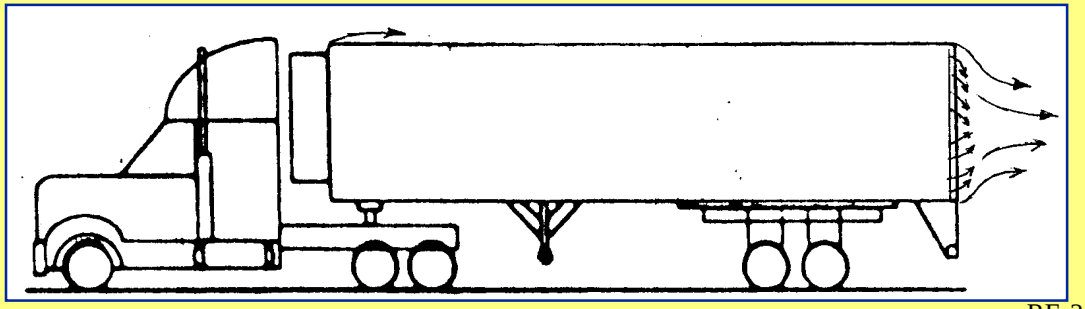
Comparative Aerodynamic & Rolling Performance Prediction, Conventional versus Pneumatic Trailer



CONCLUSIONS: Pneumatic Aerodynamic Concepts Offer Significant Potential For Application To Commercial Vehicles

- Pneumatic Devices on back of trailer, **blowing slots on all sides and/or front top**
- Separation control & base pressure recovery = **drag reduction, or**
  Base suction = drag increase
- Additional lift for **rolling resistance reduction** ($F_{Roll} = \mu N$, where N=Wt - Lift), **or**
  Reduced lift (increased download) for **traction and braking**: instantaneously **switchable**
- Partial slot blowing for **roll control & lateral stability**
- One-side blowing **(LE or TE)** for **yaw control & directional stability**
- **Aerodynamic control** of all three forces and all three moments
- **No moving parts**, negligable component drag; Very short aft addition=**no length limitation**
- **Splash, Spray & Turbulence** Reduction; Reduced **Hydroplaning**
- Use of **existing** on-board compressed **air sources** (exhaust, turbocharger, brake tank)
- **Safety of Operation**

GTRI PATENTED CONCEPTS



RECOMMENDATIONS for Program after Current Phase II

- Continued **analysis** of pneumatic improvements & **design** of full-scale configuration
- Further study of **available air supplies** and any associated penalties
- Full-scale **road demonstration** and confirmation of performance, economy, control, and stability: (ATA test rigs??)
- **Expected Program Results**:
  - Dramatic Improvement in **Aerodynamic Performance, Efficiency, Stability, Control, and Safety** of Large Commercial Heavy Vehicles
  - **No moving** external components = all-pneumatic systems and components
  - **Fast** response and Augmented Forces = **Safety of Operation**
  - **Control** of all aerodynamic forces and moments by same pneumatic system using **existing on-board air sources, driver or system controlled**
  - For **Safety & Stability**, make positive use of **aerodynamic components** (lift, download, side force, yaw, roll) **not currently employed in** Heavy Vehicle operation
  - Very **small**-size aft trailer extension; small or **no front** or top add-ons